# United States Patent [19]

**Cherry**

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[45] **Date of Patent: * Jun. 26, 1990**


[54] **HIGH-PURITY CLEANING SYSTEM, METHOD, AND APPARATUS**


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[ * ] Notice: The portion of the term of this patent subsequent to May 2, 2006 has been disclaimed.

[21] Appl. No.: **355,699**

[22] Filed: **May 23, 1989**

**Related U.S. Application Data**

[63] Continuation-in-part of Ser. No. 53,202, May 21, 1987, Pat. No. 4,832,753.

[51] **Int. Cl.**[5] ..... **B08B 5/00**

[52] **U.S. Cl.** ..... **134/22.18;** 134/10; 134/21; 134/22.19; 134/25.4; 134/26; 134/37; 134/42

[58] **Field of Search** ..... 134/10, 21, 22.18, 22.19, 134/25.4, 26, 37, 42



[56] **References Cited**

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|---|---|---|---|
| 4,443,269 | 4/1984 | Capella et al. | 134/12 |
| 4,606,774 | 8/1986 | Morris | 134/10 |
| 4,832,753 | 5/1989 | Cherry et al. | 134/22.18 |



*Primary Examiner*—Asok Pal

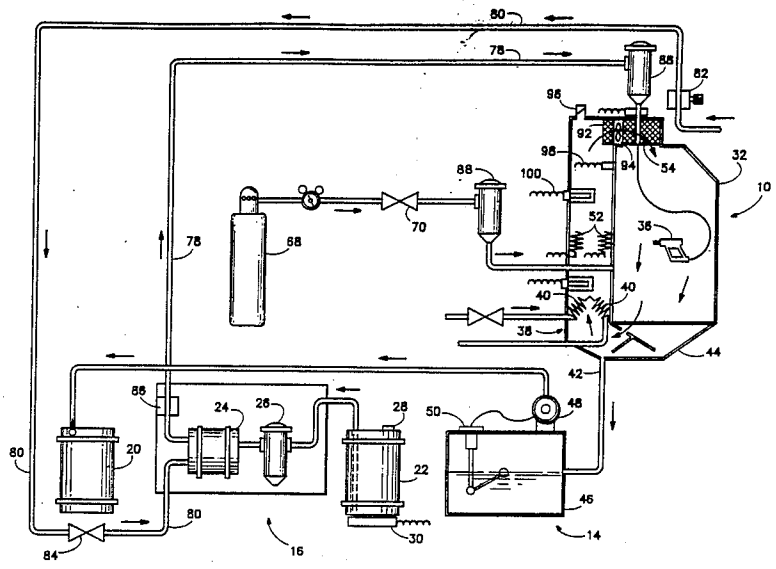
*Attorney, Agent, or Firm*—Chernoff, Vilhauer, McClung & Stenzel



[57] **ABSTRACT**

A system for high purity cleaning of components includes a cleaning chamber which is maintained at a pressure above ambient atmospheric pressure. A gas-glide transporter extends through the cleaning chamber and includes a pair of slightly tilted elongate tubes having a plurality of tiny holes therein. The tubes communicate with a source of filtered pressurized nitrogen. A tray for carrying components to be cleaned is adapted to fit on the tubes and slide down the transporter on a frictionless cushion of nitrogen. Components are cleaned of very small particles by using a high pressure spray of individual droplets of solvent which knock the particles off the component to be cleaned. The particles, solvent and solvent vapor are swept away from the component being cleaned by a stream of dry, filtered air. Two types of solvent systems are shown. One supplies liquid solvent under high pressure to the solvent sprayer while the other uses liquid solvent and a compressed gas under high pressure as a propellant to force the solvent through the small orifice of the sprayer. The cleaning chamber group includes a control panel which controls solvent supply and recovery modules. The cleaning chamber group is modular so that it may be placed in a Class **100** environment.


**6 Claims, 4 Drawing Sheets**



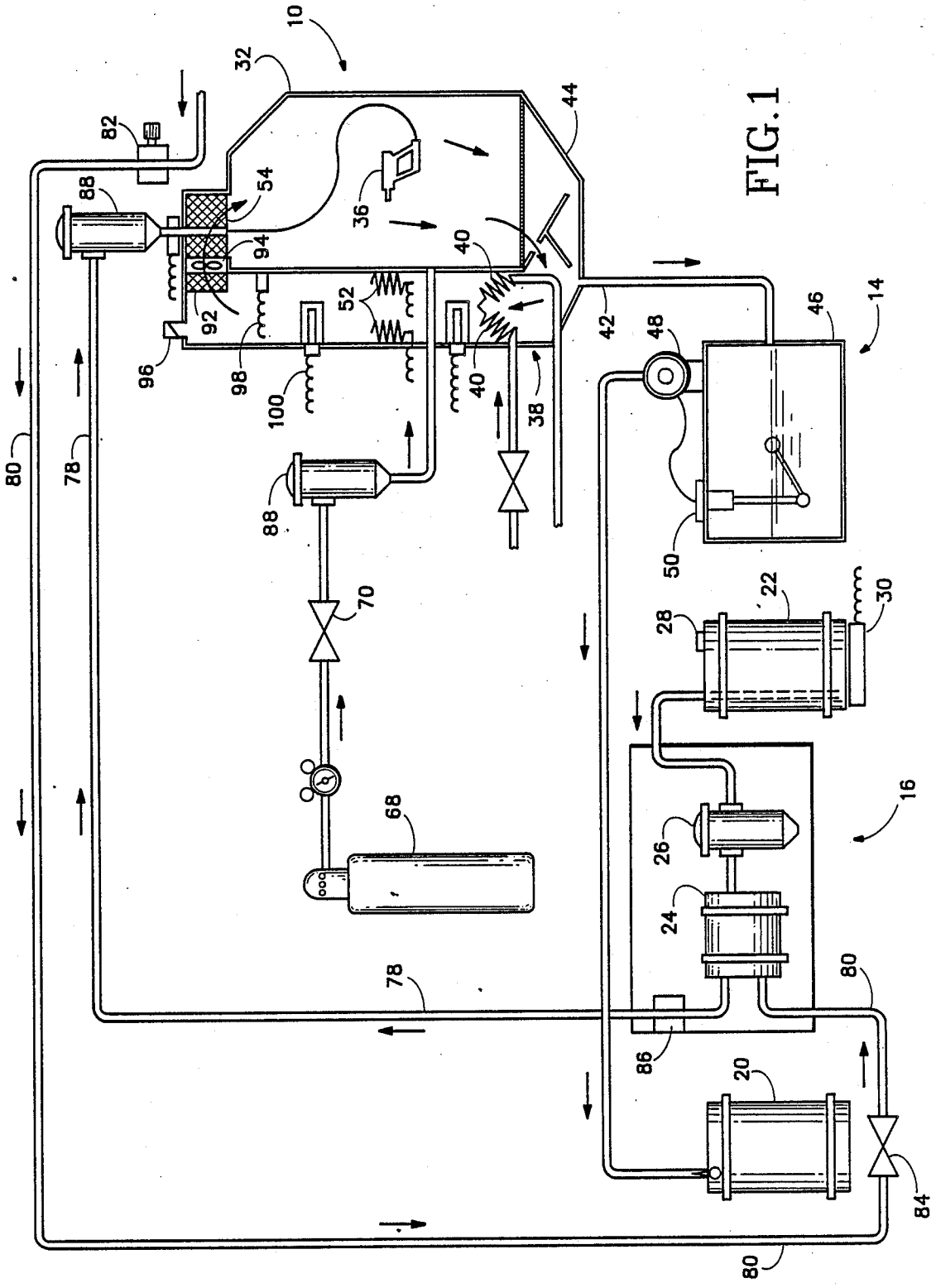
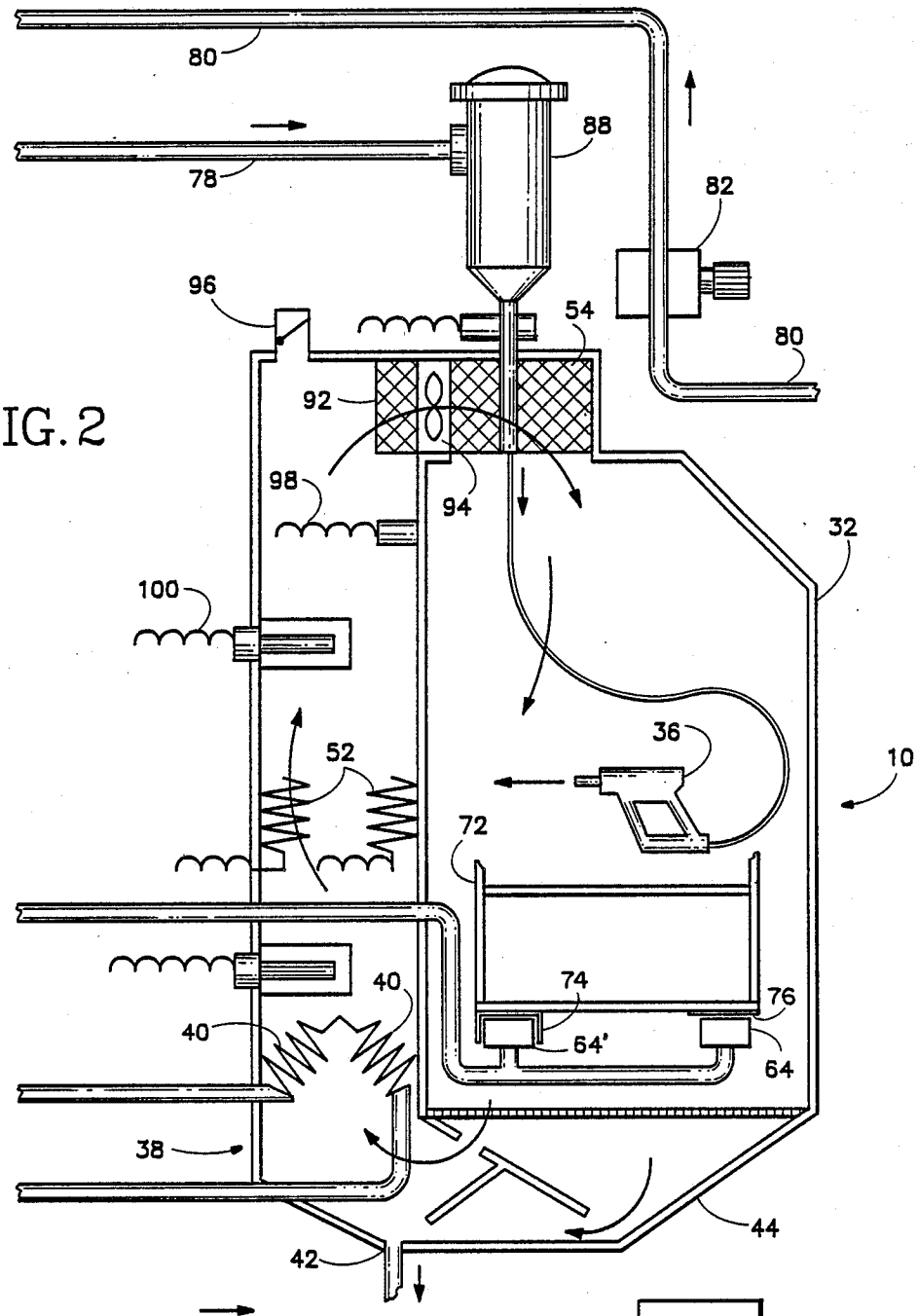

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FIG. 1

FIG. 2


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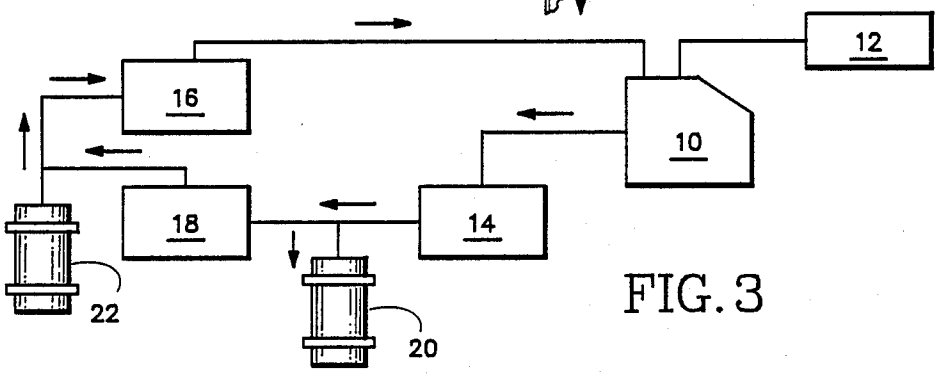

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FIG. 3

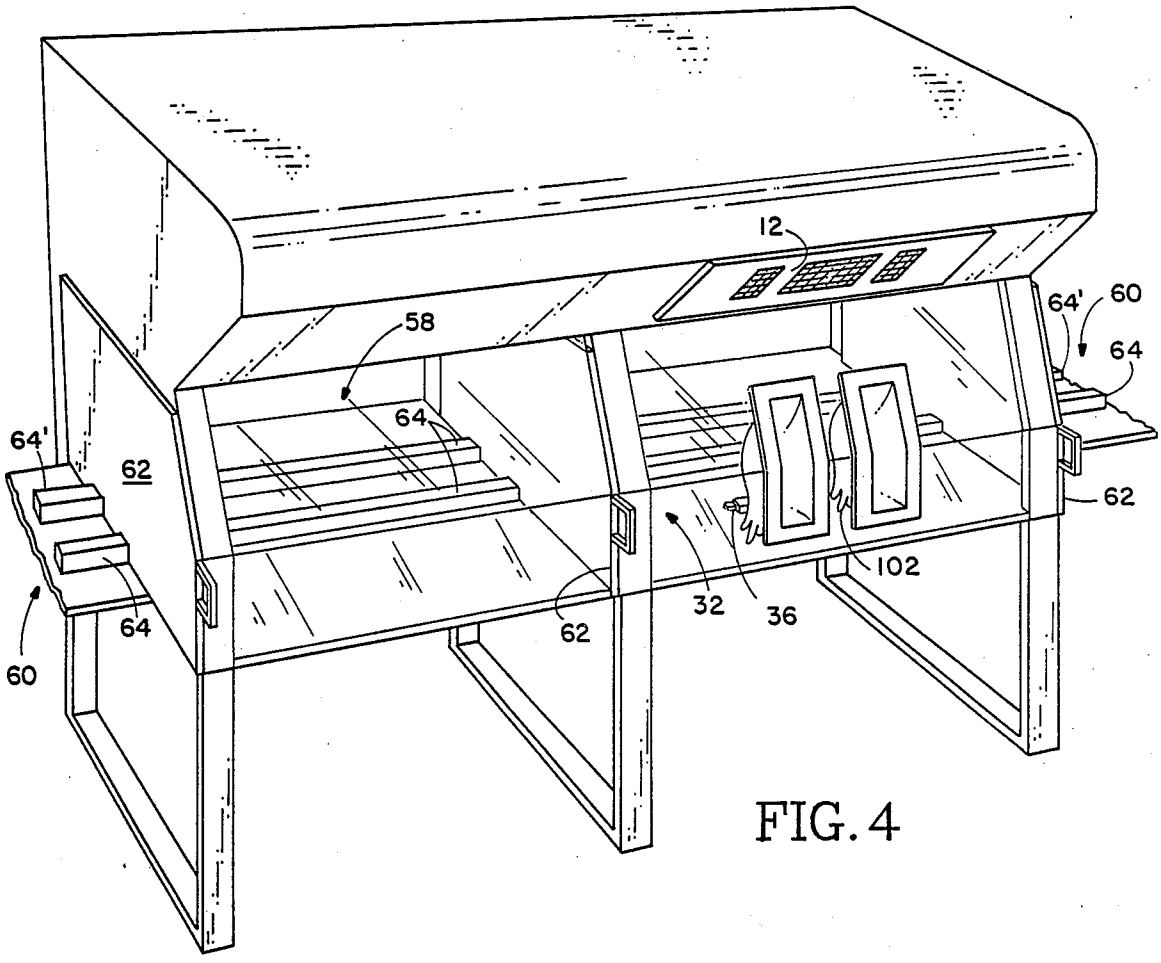



FIG. 4

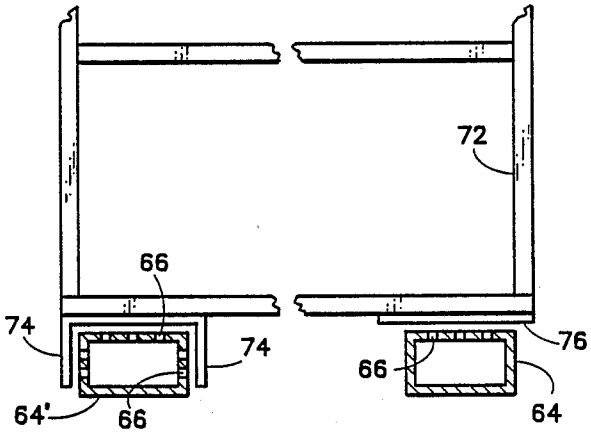



FIG. 5

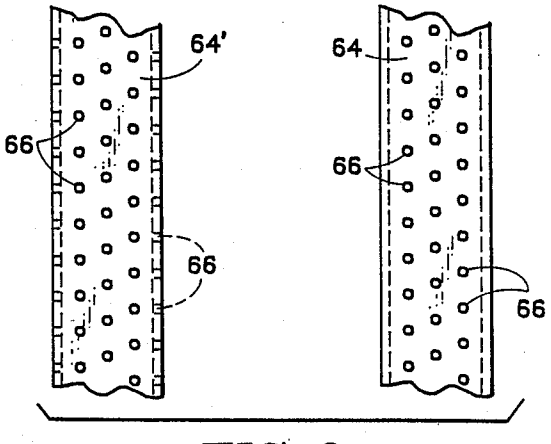



FIG. 6

FIG. 7

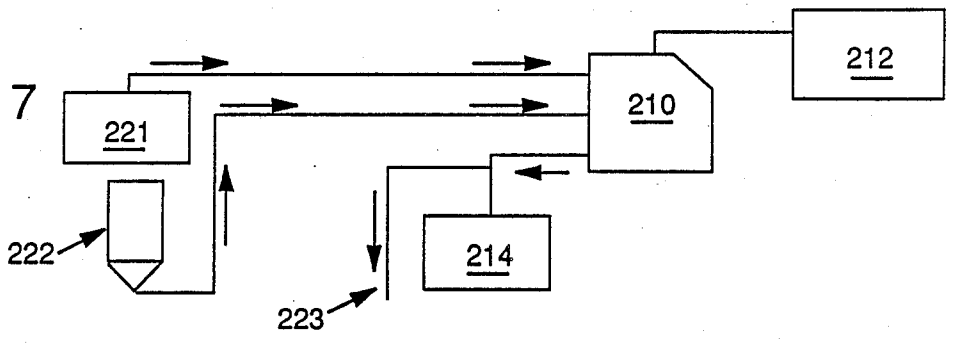
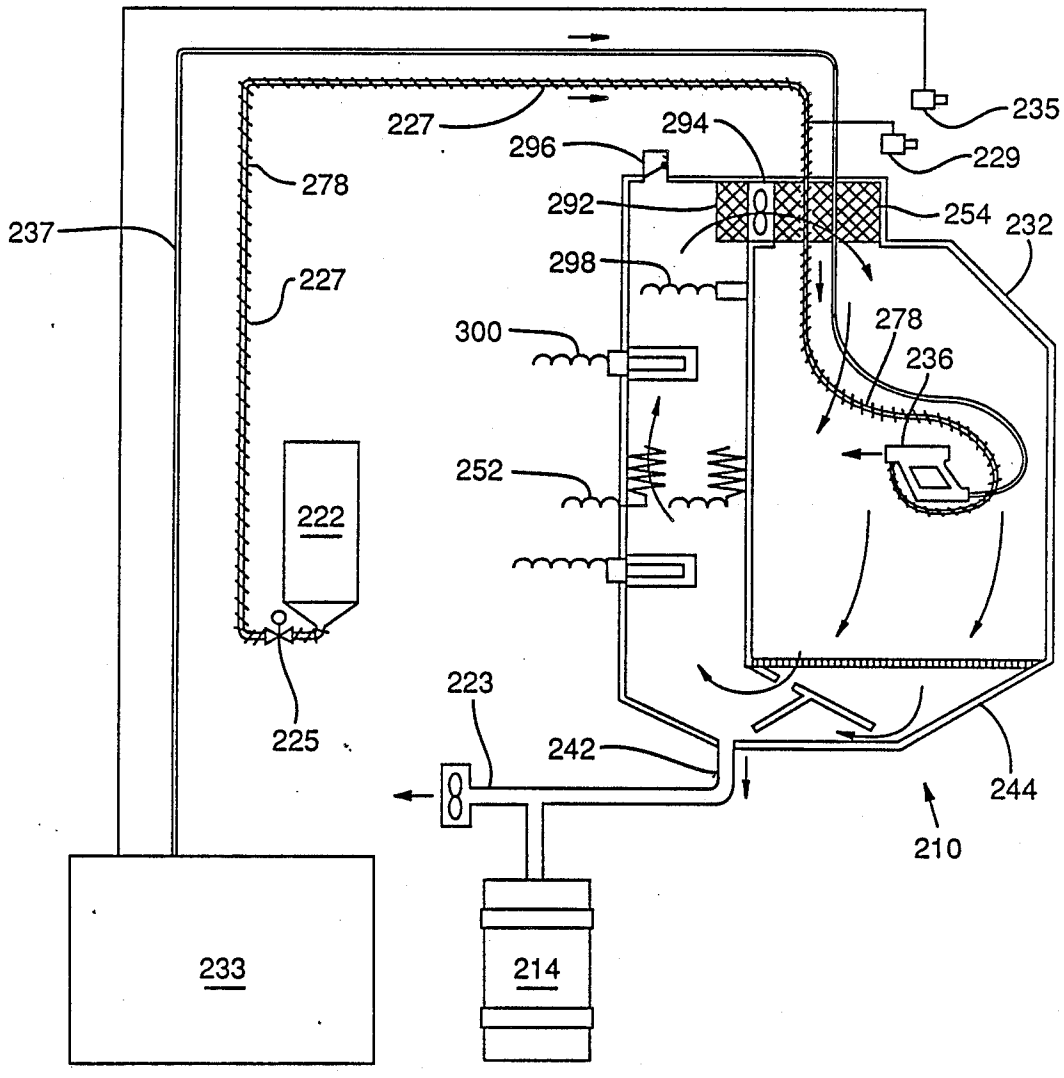

212
210
221
222
214
223

FIG. 8


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# HIGH-PURITY CLEANING SYSTEM, METHOD, AND APPARATUS

This is a continuation-in-part of Application Ser. No. 07/053,202, filed May 21, 1987, now U.S. Pat. No. 4,832,753.

## BACKGROUND OF THE INVENTION

This invention relates to a system, method, and apparatus for high-purity cleaning of manufacturing components, and particularly to such a system, method, and apparatus which enable components to be cleaned, dried, and packaged in a clean environment.

Certain industries, such as manufacturers of silicon chips or other semi-conductors, require that manufacturing and storage components be extremely clean, substantially free of contaminant films and micron and sub-micron particle contamination One method of high-purity cleaning is to wash the items to be cleaned with a high-pressure (2000–2400 psi) spray of solvent as described in Capella et al. U.S. Pat. No. 4,443,269. However, the process and apparatus disclosed in Capella are designed specifically for the removal of radioactive particles and contaminants and are not particularly suited to clean an item for future use so that the item becomes and remains substantially free of all contaminants and particles, not merely free of radioactive contaminants and particles.

For example, the method of Capella employs a cleaning chamber having sub-atmospheric pressure so that radioactive particles do not "blow" out of the chamber. This creates the possibility that non-radioactive particles proximate the cleaning chamber will be drawn into the chamber, especially when the chamber is opened to remove a component from the chamber. Since Capella is concerned primarily with radioactive particles, Capella's system filters particles out of the solvent and then reuses the filtered solvent, which could contain dissolved contaminants

The solvents typically used in systems of the type described above are from the chlorofluorocarbon group (CFC) such as freon, and are now considered undesirable because it is thought that such gases deplete the ozone layer. Accordingly, it would be preferable to use a solvent which does not have negative health or enviromental considerations. A solvent which could be safely vented directly to the atmosphere without the need for a solvent recovery system would also be highly desirable.

## SUMMARY OF THE INVENTION

The present invention provides a system, method, and apparatus for high-purity cleaning of components and for maintaining the components in a clean condition during drying and packaging. The system according to the present invention is modular, so that the cleaning chamber and the system controls may be isolated within a class 100 clean environment, with the "dirty" components located remote from, or sealed off from, the cleaning chamber and controls

The cleaning chamber of the system includes an air delivery and filtration system that directs a stream of dry, warm, filtered air directly onto the items being cleaned while the item is simultaneously being sprayed with a high-pressure dispersion of solvent droplets. The air flow provided by the air system is sufficient, in volume and purity, to make the inside of the cleaning chamber a Class 10 environment. The air system maintains the pressure in the cleaning chamber above ambient atmospheric pressure.

The cleaning system also includes a solvent pumping and spraying system capable of delivering a spray of solvent at up to 6000 psi. The combination of high pressure and a small spraying orifice acts to create a spray of tiny solvent droplets which act as "fluid hammers" to knock very small, sub-micron particles off of the components to be cleaned, dispersing the particles into the chamber where they are carried away by the stream of clean, dry air flowing over the item and through the chamber.

An alternative system employs liquid $CO_2$ as a solvent, avoiding the environmental and health-related drawbacks of other commonly used solvents. Liquid $CO_2$ is supplied at one pressure and combined with a gaseous propellant under very high pressure to create the spray of tiny droplets.

The droplets which comprise the high pressure spray have a slight positive charge whereas ions associated with the contaminant particles typically have a slight negative charge Thus, the contaminant particles tend to adhere to the solvent after they have been knocked off the item to be cleaned.

For automated cleaning, the cleaning chamber includes a gas-glide transporter for moving the components to be cleaned into, through, and out of the cleaning chamber without substantially introducing extraneous particulate contamination into the chamber.

The cleaning chamber may be constructed to any size and may be adapted to cooperate with an adjacent drying chamber, which, like the cleaning chamber, may be operated at an environment down to Class 10.

Accordingly, it is a principal object of the present invention to provide an improved high-purity cleaning system, method, and apparatus.

It is a particular object to provide such a system, method, and apparatus which not only cleans the material of pre-existing contaminants, but prevents contamination during cleaning, drying, and packaging.

It is an associated object to provide a cleaning system having a positive pressure within the cleaning chamber.

It is a further object to provide a system which supplies the cleaning chamber with a flow of dry, warm, filtered air sufficient to maintain a Class 10 environment.

It is another object to provide a cleaning system to clean objects with a very high-pressure solvent spray of tiny droplets to knock particles off of the components to be cleaned.

It is a further object to provide a cleaning system which can transport material into, through, and out of the cleaning chamber substantially without the introduction of extraneous contaminants.

It is another object to provide a system having a cleaning chamber and a control system which can be operated within a clean environment with other components of the system remote or sealed off from the clean environment.

It is an additional object to provide a system and method employing an environmentally safe solvent.

It is a further object to provide a system and method which employ electrostatic principles to remove contaminant particles from the item to be cleaned and to prevent such particles from re-adhering to the item.

The foregoing and other objectives, features, and advantages of the invention will be more readily under-

stood upon consideration of the following detailed description of the invention, taken in conjunction with the accompanying drawings.

## BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a schematic view of an exemplary system according to the present invention.

FIG. 2 is a schematic view of an exemplary cleaning chamber including air supply system, condensate system, and gas-glide transporter.

FIG. 3 is a schematic view of an exemplary system including a distillation group.

FIG. 4 is an artist's view of an exemplary cleaning chamber group including a control panel, a drying chamber, and a gas-glide transporter.

FIG. 5 is an elevational view of a cleaning tray mounted on a cross-section of the gas-glide transporter.

FIG. 6 is a partial top view of the gas-glide transporter shown in FIG. 5.

FIG. 7 is a block diagram of an alternative system according to the present invention.

FIG. 8 is a schematic view of the alternative system of FIG. 7.

## DETAILED DESCRIPTION OF THE INVENTION

FIGS. 1–6 show one exemplary embodiment of the cleaning system of the present invention, and features thereof.

Starting with FIG. 3, an exemplary cleaning system according to the present invention includes a cleaning chamber group **10**, a control system **12**, a used solvent recovery group **14**, and a pump group **16**. If the system is distilling and reusing the newly distilled solvent, a distillation group **18** is located between the used solvent recovery group and the pump group. If the system is using new solvent, the recovered solvent is fed to a used solvent container **20**, and new solvent is supplied to the pump group from a new solvent container **22**.

Turning to FIG. 1, an exemplary embodiment of a system which does not use a distillation group includes a cleaning chamber group **10**, a used solvent recovery group **14**, a pump group **16**, new solvent container **22**, and a used solvent container **20**. The basic operation of the system may be explained by tracing the flow of solvent through the system

A positive displacement, high-pressure pump **24** draws new, clean solvent out of container **22**, through filter **26** and pushes the new solvent through the solvent supply line **78** toward the location of the cleaning chamber group. The pump is an airless type pump which is adapted to supply a liquid, under pressure, without air entrained in the liquid. The pump is powered by a regulated supply of air pressure, such as "factory air" through the pump control air line **80**. A regulator **82** ensures that air is supplied to the pump at a constant pressure. The pump control air line **80** includes an emergency shutdown valve **84** to shut down the pump if the control system **12** senses a dangerous situation.

The pump is "on demand," it does not operate unless pressure in the solvent supply line **78** falls below a predetermined level. The use of an on-demand pump is important for several reasons. An operating pump, with parts moving against other parts, has a tendency to shed particles. A pump which operates continuously also has a tendency to heat up, which increases particle shedding. An on-demand pump also eliminates the need for complex valving to relieve the pressure created by constant operation. A pump which has very few moving parts which are wetted, i.e. touched by the solvent, is well suited for this purpose.

The primary purpose of filter **26**, preferably a 400 mesh filter which is capable of filtering particles as small as 1–2 microns, is to ensure that such particles do not enter into and score the inner working surfaces of the pump which operates with rather small tolerances A 0.2 micron vent filter **28** on the new solvent container ensures that particles are not drawn into the container when air enters the container through the vent. A load cell **30**, detects the weight of the new solvent container and is operatively connected to the control system to alert the operator, or to shut down the system, when the container is nearly empty.

Following the flow of solvent downstream from the pump, a surge surpresser **86** dampens out surges caused by sudden operation of the pump. Prior to entering the cleaning chamber **32** the new solvent passes through another filter **88** adapted to filter out all particles larger than 0.2 microns. A pressure transducer **34**, downstream of the filter, provides the operator with a readout of the pressure in the solvent supply line at the control panel and can cause the valve **84** in the pump **25** control air line **80** to close if the pressure in the solvent supply line becomes too high.

In the cleaning chamber, the solvent is fed to a solvent gun **36** through a flexible hose and is shot from the solvent gun in a very high-pressure spray of tiny droplets whose impact is sufficient to actually knock submicron particles off the surface of the component being cleaned The combination of a very high-pressure (2,500–6,000) and a relatively small orifice (less than twenty thousandths) on the solvent gun yield a solvent spray which is characterized by very small, fast-moving droplets traveling in excess of 100 meters per second at approximately 4"–18" from the orifice of the solvent gun. The droplets act as a "fluid hammer" to actually knock particles off the component to be cleaned. Closer to the orifice the spray has not yet had an opportunity to form a dispersion of droplets, while further than 18" from the orifice the solvent may partially vaporize, reducing its effectiveness at cleaning. The high pressure and small orifice result in a flow of 0.5–1.0 gallons per minute, a substantial savings over other systems which use much more solvent without cleaning as effectively.

Applicant believes that Capella, which discloses a system which delivers "solvent at a range of 4–4.6 gallons per minute at a pressure in the range of 2,000–2400 pounds per square inch," actually delivers multiple streams of liquid solvent onto the article to be cleaned. A stream of liquid solvent flowing over a surface does not have the same mechanical impact as a dispersion of individual droplets impacting the surface. When liquid flows over a surface, a thin, boundary layer of essentially zero velocity is created. Small submicron particles can "hide out" in this boundary layer or hide out in eddys in the solvent flow caused by small surface irregularities. Comparatively, individual droplets, from a source of the identical pressure, can create three to four times the impact on a small particle than can a stream of fluid.

In addition to the fluid hammer effect of the tiny droplets, applicant directs a strong flow of dry, filtered air over the item being cleaned and through the chamber. The air flow is introduced at the top of the chamber and drawn out through the bottom of the creating a strong, substantially laminar flow of air through the

chamber. This air stream carries the solvent droplets, solvent vapor, and free particles away from the item being cleaned so that particles do not readhere to the wet surface. While free particles are carried away with the solvent vapor other particles are likely to become bound to the solvent droplets.

Applicant has found that creating the high pressure, high speed, dispersion of individual solvent droplets imparts a slight positive charge to the solvent droplets. Ions typically associated with contaminant particles give the particles a slight negative charge, while the item to be cleaned typically has a slight positive charge. When the contaminant particles are knocked off the item to be cleaned, the slight positive charge of the droplets tend to cause the negatively charged contaminant particles to adhere to the solvent droplets and/or solvent vapor and be swept away in the air stream rather than re-adhering to the item to be cleaned. Applicant believes that this beneficial electrostatic effect does not occur when a contaminated item is washed with a stream of solvent, even a relatively high pressure stream.

The air supply system of the present invention moves a sufficient volume of very clean, dry air through the cleaning chamber to meet the requirements for a Class 10 environment as described in Federal Standard 209(c) of the "Federal Standard Clean Room and Work Station Requirements, Controlled Environment." The clean, dry air, which is maintained near ambient temperature, flowing past the article being cleaned at approximately 50 feet per minute tends to dry the article very quickly thereby discouraging subsequent particle readhesion common to wetted surfaces.

As the spray of solvent droplets travels further away from the gun, some of the solvent may vaporize because the pressure in the chamber, which is slightly above atmospheric pressure, is much less than that of the pressurized solvent. The vaporized solvent as well as the other air in the chamber is drawn out of the bottom of the chamber and up through a condensor **38** including cooling coils **40** which cool the vapor/air mixture from the chamber so that the solvent condenses and drains out of the chamber through a drain **42**. Liquid solvent in the chamber would also be directed toward the drain by the V-shaped bottom **44** of the chamber. The used solvent is collected in a recovery tank **46** including a pump **48** and a float switch **50** which automatically pumps the used solvent to the used solvent container **20**.

After the solvent has condensed out of the chamber atmosphere, the remaining air is drawn up past heating coils **52** which raise the temperature of the air to compensate for the cooling effect of the condensor. The heating coils are controlled by a thermo-couple **100** to raise the temperature of the air up to or above ambient temperature. The air is then drawn through a pre-filter **92** and a fan **94**, and pushed through a high efficiency particle air ("HEPA") filter **54** to remove any free particle contaminants in the air. The HEPA used by applicant can remove 99.99% at 0.3 microns. The dissolved contaminants and particulate contaminants which become bound to the solvent were carried away with the condensed solvent.

In order to maintain the pressure within the cleaning chamber above atmospheric pressure, a make-up air damper **96** is controlled by a pressure transducer **98** to add sufficient air to keep the pressure in the chamber above atmospheric pressure. The air supply system exchanges the air in the cleaning chamber approximately every 10 seconds.

Turning to FIG. **4**, an exemplary cleaning chamber **32** is shown. A control panel **12** is co-located with the cleaning chamber. The control panel is connected to the various valves, sensors, and controls discussed above so that the operator can monitor and control the entire system from his position at the cleaning chamber. The operator can reach into the cleaning chamber to operate the solvent gun and manipulate the components to be cleaned through a pair of gloves **102** which are sealed in a see-through wall of the chamber. A drying chamber **58** is arranged next to the cleaning chamber and, like the cleaning chamber, is also sealed. In the exemplary embodiment shown in FIG. **4**, the air system would provide the same flow of clean, dry air to the drying chamber as has been described with respect to the cleaning chamber. A door **62** between the cleaning and drying chambers may be opened by the operator to move articles from the cleaning chamber to the drying chamber. Similar doors **62** on the entrance to cleaning chamber and the exit from drying chamber permit articles to be moved into and out of the chambers. A gas-glide transporter **60** extends through the cleaning and drying chambers.

With attention to FIGS. **1**, **2**, **5**, and **6**, as well as FIG. **4**, the gas-glide transporter includes a pair of rectangular tubes **64** and **64'**. As shown in FIG. **6**, the top of tube **64** includes many small holes **66** **5** in a biased pattern while the top and both sides of the guide tube **64'** also include such holes in a similar pattern. Except for these small holes, the tubes are otherwise airtight and are fed with a pressurized filtered gas such as nitrogen ($N_2$) as shown in FIG. **1**. A bottle of $N_2$ **68** under pressure, controlled by a valve **70** and passing through a 0.2 micron filter **88**, is fed into the cleaning chamber and into the gas-glide tubes **64** and **64'** as shown in FIG. **2**.

As shown in FIG. **4**, a cleaning tray **72** is adapted to be supportably guided by the tubes. The cleaning tray includes one supporting foot **74** which fits over the top and sides of the guide tube **64'** and a supporting sole **76** which is positioned over the top of the other tube **64**. The tubes are slightly slanted so that the infeed end of the tubes near the cleaning chamber is slightly higher than the outfeed end near the drying chamber. When pressurized nitrogen is fed to the tubes, the tray is supported by a frictionless cushion of $N_2$ between the foot and sole of the tray and their respective tubes. Since the tubes are slanted, the tray will glide down the tube toward the lower end. When the supply of $N_2$ is cut off, the tray settles directly onto the tubes and the friction between the tray and the tubes prevents the tray from moving. In this fashion movement of the tray into, through, and out of the chambers may be completely and precisely controlled by the operator through the control system from his position at the cleaning chamber.

Typical transport systems such as belts or chains, which are powered by motors, and supported by bearings or journals, tend to be "dirty" in that they have many moving parts which can generate and shed particles. The gas-glide disclosed above has no moving parts and is not apt to introduce any particles or other contaminants into the chamber since the $N_2$ is filtered prior to entering the chambers.

As previously noted, doors **62** at either end of the chamber may be opened by the operator to permit the components to be placed or transported into or out of

the chambers. Several techniques eliminate or reduce the introduction of particles into the chambers when the chambers are opened. First, the modular design of the system enables the "dirty" functions of the system to be located remote from the cleaning chamber and control system so that the cleaning chamber itself may be placed in a clean environment, up to class **100**. Pumps, motors and other components of the system which would not be able to operate in a class **100** environment are enclosed or separated from the cleaning chamber group. Placing the cleaning chamber in such a clean environment reduces the possibility of contamination when the chamber is opened. In addition, the chamber of the present invention is maintained at a pressure which is above atmospheric pressure, causing air to flow out of the chambers when the chamber doors are opened.

The system and method have been described above in operation with a solvent such as Freon. Other solvents such as denatured alcohol, carbon tetracloride, or dionized water, or combinations of solvents, would behave somewhat differently. For example, when alcohol is used as a solvent, there would be less vaporization than Freon, and when deionized water is used there would be virtually no vaporization. However, operation of the system would be essentially the same, with more of the solvent running out of the chamber as a liquid and less being condensed out of the chamber atmosphere.

FIGS. **7** and **8** show an alternative embodiment of the cleaning system of the present invention. In many respects the alternative system shown in FIGS. **7** and **8** is very similar to that described above with respect to FIGS. **1–6**. Like the first system, the alternative system cleans by creating a high pressure spray consisting primarily of individual droplets of solvent traveling at a high rate of speed to knock contaminant particles off the item to be cleaned. Simultaneously, with this "fluid hammer" spray, a laminar flow of warm, dry, filtered air is passed over the item to be cleaned carrying away solvent vapor and contaminant particles which have been knocked off the item. As with the previously described system, the chamber is capable of being substantially sealed from the atmosphere and a slight positive pressure is maintained in the chamber to ensure that contaminants are not drawn into the chamber.

The major difference in the alternative system is that rather than supplying the solvent sprayer with a solvent under high pressure (above 2500 psi), the system supplies the sprayer with liquid solvent at a first pressure and also with a gas propellant at a second, higher, pressure. Another major difference between the systems is that the alternative system uses a liquid solvent such as $CO_2$ which is environmentally safe and can be vented directly to the atmosphere.

Starting with FIG. **7**, a block diagram of the alternative system includes a cleaning chamber group **210**, a control system **212**, a solvent recovery group **214**, a solvent supply **222**, and a compressed gas supply **221**. If the solvent is not to be recovered, and can be safely vented to the atmosphere, an exhaust vent **223** is shown.

Turning to FIG. **8**, the cleaning chamber group **210** includes the chamber itself **232** and a solvent sprayer **236** for dispersing a high pressure spray of solvent droplets. Pure liquid $CO_2$ is supplied to the sprayer through a solvent supply line **278** from a container **222** of compressed liquid $CO_2$. Liquid $CO_2$ at approximately 300 psi is readily available. If necessary, the liquid $CO_2$ may be filtered to achieve the requisite purity. A solenoid valve **225** in the solvent supply line controls the supply of liquid $CO_2$ to the solvent sprayer **236**.

The solvent supply line is heat wrapped with electrical heating tape **227** to maintain the liquid $CO_2$ at ambient temperatures, preferably above 60° F. A disruption in the substantially laminar flow of the $CO_2$ within the solvent supply line could allow air bubbles which may be inside the supply line to combine with the $CO_2$ and and allow some liquid $CO_2$ to enter a gaseous phase. This change of phase removes heat (heat of vaporization) from the surrounding liquid $CO_2$ which could cause the liquid $CO_2$ to freeze into dry ice and clog the solvent supply line. Accordingly, it is important to keep the liquid $CO_2$ at a sufficiently high temperature so that such freezing and clogging does not occur. A heat control **229** enables the heating of the solvent supply line to be adjusted as required.

The solvent sprayer is also supplied with a supply of filtered gas, such as air, under high pressure (3000 psi). The air is supplied through air supply line **237** by a compressor **233** such as an "on demand" pure oxygen compressor, which is controlled by a suitable control device **235**.

The compressed air at 3000 psi and liquid $CO_2$ at 300 psi are combined in the solvent sprayer immediately adjacent a small (less than 0.002") orifice so that the solvent is forced through the orifice under high pressure so as to form a spray of individual solvent droplets. The flow rate of the liquid $CO_2$ is less than 0.3 gallons per minute. It may also be possible to combine the liquid $CO_2$ and compressed air in a mixing chamber prior to exiting the orifice. Appropriate valving and venturis within the solvent sprayer prevent the 3000 psi compressed air from backing up the 300 psi liquid $CO_2$ line.

The remainder of the cleaning chamber group is essentially as described above with respect to the embodiment depicted in FIGS. **1–6**. After exiting the chamber **232**, the air is drawn up past heating coils **252** controlled by thermo-couple **300**, through a pre-filter **292**, and a fan **294** into the chamber. A make-up air damper **296** is controlled by a pressure transducer **298**. Most of the liquid $CO_2$ vaporizes in the cleaning chamber. As the air and $CO_2$ vapor leave the chamber through the V-shaped bottom **244**, the heavier $CO_2$ vapor is drawn out through the drain **242** by the exhaust fan at vent **223**. Any liquid solvent will drain into a solvent recovery container **214**.

The gas glide transporter described above with respect to FIGS. **1–6** is compatable with the alternative embodiment shown in FIGS. **7** and **8**.

Although the alternative embodiment has been described employing compressed air and liquid $CO_2$, other compressed gases are also suitable and other solvents may also be suitable if they have similar characteristics to $CO_2$ and Freon TF such as viscosity, temperature range, and ability to remove non-volatile residue, mainly hydrocarbons.

The terms and expressions which have been employed in the foregoing specification are used therein as terms of description and not of limitation, and there is no intention, in the use of such terms and expressions, of excluding equivalents of the features shown and described or portions thereof, it being recognized that the scope of the invention is defined and limited only by the claims which follow.

What is claimed is:

**1**. A method of high purity cleaning including particle removal from an item to be cleaned, comprising:

(a) placing an item to be cleaned in a chamber which is capable of providing a clean environment;

(b) providing a high pressure solvent sprayer for directing and dispersing a spray consisting of individual droplets of solvent upon said item to be cleaned;

(c) striking said item to be cleaned with said droplets of solvent dispersed from said sprayer so as to dislodge contaminant particles from said item; and

(d) providing said sprayer with a supply of liquid solvent at a first pressure above ambient pressure and a supply of gaseous propellant at a second pressure above said first pressure, said second pressure being above 2500 psi.

2. The method of claim 1 wherein said liquid solvent includes $CO_2$.

3. The method of claim 2, including the step of providing heating means for maintaining the temperature of said supply of liquid $CO_2$ above ambient temperature.

4. The method of claim 1, including the step of forcing said solvent through an orifice at said second pressure, said orifice having a diameter of less than 0.002 inch.

5. The method of claim 1, including the step of forcing said solvent through an orifice at said second pressure wherein said solvent and said propellent are combined immediately prior to passing through said orifice.

6. The method of claim 1 wherein said item to be cleaned has a slight positive charge, ions associated with said particles have a slight negative charge and said individual droplets have a slight negative charge so that said particles adhere to said solvent after being dislodged from said item to be cleaned.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION

PATENT NO. : 4,936,922

DATED : June 26, 1990

INVENTOR(S) : Roger L. Cherry

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

On the title page, item [*] Notice, should read as follows:

--The portion of the term of this patent subsequent to May 23, 2006 has been disclaimed.--

**Signed and Sealed this**

**Sixth Day of October, 1992**

*Attest:*

DOUGLAS B. COMER

*Attesting Officer*

*Acting Commissioner of Patents and Trademarks*

UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION



PATENT NO. : 4,936,922

DATED : June 26, 1990

INVENTOR(S) : Roger L. Cherry

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

| | | |
|---|---|---|
| Col. 1, | Line 19 | After "contamination" insert a --.-- |
| Col. 1, | Line 40 | After "contaminants" insert a --.-- |
| Col. 1, | Line 61 | After "controls" insert a --.-- |
| Col. 2, | Line 23 | After "charge" insert a --.-- |
| Col. 4, | Line 8 | After "tolerances" insert a --.-- |
| Col. 4, | Line 24 | Change "pump 25" to --pump-- |
| Col. 4, | Line 32 | After "cleaned" insert a --.-- |
| Col. 4, | Line 56 | Change "submicron" to --sub-micron-- |
| Col. 4, | Line 67 | Before "creating" insert --chamber-- |
| Col. 5, | Line 3 | Change "readhere" to --re-adhere-- |

UNITED STATES PATENT AND TRADEMARK OFFICE

# CERTIFICATE OF CORRECTION

PATENT NO. : 4,936,922



DATED : June 26, 1990

INVENTOR(S) : Roger L. Cherry

It is certified that error appears in the above-identified patent and that said Letters Patent is hereby corrected as shown below:

| | | |
|---|---|---|
| Col. 6, | Line 29 | After "66" delete --5-- |
| Col. 7, | Line 20 | Change "tetracloride" to --tetrachloride-- |
| Col. 7, | Line 20 | Change "dionized" to --deionized-- |
| Col. 8, | Line 9 | Before "allow" delete --and-- |

Signed and Sealed this

Eighth Day of December, 1992

*Attest:*

*Attesting Officer*

DOUGLAS B. COMER

*Acting Commissioner of Patents and Trademarks*